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6. AUTHOR(S)
David J. Brady

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Department of Electrical and Computer Engineering Duke University, PO Box 90291 Durham NC 27708-0291	

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13. ABSTRACT (Maximum 200 words)

The objective of this research is the development of a low cost sensor system with applications in biometric tracking and authentication. We have demonstrated the ability to classify and track human motion using low cost, off- the-shelf pyroelectric detectors. We have designed fieldable sensor units that are anonymous and can perform multiple tasks such as biometric classification, multiple object tracking, and camera pointing. We have demonstrated the ability to track two individuals and demonstrated the ability to recognize multiple humans with an accuracy of 86%. We have integrated the units through wireless communication to allow the creation of a cluster field of detectors.

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Final Progress Report

Discrimination, Identification, and Tracking of Unresolved Targets Using Tomographic Integration of Multiplex Sensor Data

20 December 2006

Statement of the problem

We propose the development of a low cost sensor system that has potential applications in biometric tracking and authentication. Our target application is to classify human motion using low cost, off- the-shelf pyroelectric detectors, that will be anonymous and can perform multiple tasks such as biometric classification, camera pointing, and integration with other sensor modalities such as acoustics to provide an integrated cluster field of detectors.

Summary of the most important results

Conventional biometrics implementations involve the use of cameras or infrared imagers to gather either brief, high resolution measurements in the case of retinal or iris scanners, or short range, low bandwidth measurements as with fingerprint or gait recognition algorithms. Biometrics are principally for local authentication and often sacrifice bandwidth and computational efficiency for low false-positive detection, tracking applications on the other hand, are designed for longer range operation and trade resolution for field of view. Our unique approach, that allows us to accomplish the research objective, is the use of coded apertures which spatially modulate the sensors visibility.

We have designed and developed a low-cost pyroelectric detector based IR motion-tracking system. Our approach is novel in its emphasis on integrated computational sensors, in its attention to sensor sampling topology, system geometries, data efficiency and computational complexity and in its integration of heterogeneous sensor modalities. We have developed reference structure based thermal infrared sensors. A single platform has eight pyroelectric detectors accompanied with Fresnel lens arrays, an amplifier board, and an integrated micro-controller/transceiver board for on-board processing and wireless communication. The sensors have been designed to sample human visual signatures according to algorithmically matched geometries. We have studied the characteristics of the detector and the Fresnel lenses that are used to modulate the visibility of the detectors. The optimal element number of the lens array for the identification system was investigated and the experimental results suggest that the lens array with more elements can yield a better performance in terms of identification and false alarm rates. The other parameters of the system configuration such as the height of sensor location and sensor-to-object distance were also studied to improve spectral distinctions among sensory data of human objects.

A theory has been developed to guide in the design of spatial mappings for segmenting a tracking space. The map allows the use of boundary sensor arrays for object tracking. Analysis of both 1D and 2D spaces based on graph theory has been made.

To accomplish classification of motion, to sort people into groups, and to classify the tasks they are performing, we have used two approaches using the mapping patterns generated by the spatially visibility maps. In the first approach the temporal signal produced by the detector is represented by an n-dimensional vector whose length is associated with the temporal duration of the detector signal but whose components are based on features of the temporal signal. In the second approach, frequency analysis of the temporal signals has been used to classify the motion of people into classes.

We have developed algorithms and sensor distribution and sampling design and placed them in a testbed facility on the Duke campus. The sensors have been designed to work in heterogeneous arrays covering a large indoor area. We have demonstrated the ability to track a two individuals in an enclosed room using two different sensor designs. We have also demonstrated the ability to identify multiple humans with a success rate of 86%. In the frequency analysis approach the recognition was accomplished using Principal component analysis of the spectral content of the tracking signals. The detector array with masked Fresnel lens arrays was also used to generate digital sequential data that can represent a human

motion feature. Hidden Markov models (HMMs) were trained to statistically model the motion features of individuals through an expectation-maximization (EM) learning process. Human subjects were recognized by evaluating a set of new feature data against the trained HMMs using the maximum-likelihood (ML) criterion.

We have also been able to recognized the performance of different tasks by an individual.

(6) **Publications:**

(a) Peer-reviewed:

i. David J. Brady, Nikos Pitsianis., Xiaobai Sun, Reference structure tomography. *JOSA A,* 2004. **21**(7): p. 1140-1147.

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iv. Qi Hao, David J. Brady, Bob D. Guenther, John B. Burchett, Mohan Shankar, and Steve Feller, "Human Tracking With Wireless Distributed Pyroelectric Sensors, *IEEE Sensors J,***Vol 6***,* 6, Dec 2006, pp1683-1696*.

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vi. Q. Hao, J.-S. Fang, D. J. Brady, B. D. Guenther, and M. Shankar, "Multiple human tracking with wireless geometric pyroelectric sensors," *IEEE Sensors J.*, submitted, 2006

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xi. Q. Hao, D. Brady, B. Guenther, J. Burchett, and M. Shankar, "Human tracking with wireless distributed radial pyroelectric sensors", Submitted to IEEE Sensors, 2005.

xii. M. Shankar, J. Burchett, B. Guenther, and D. Brady, "Characterization of Pyroelectric Infrared Detectors for Human Tracking", Submitted to Optical Engineering, 2005.

xiii. 8. J. Burchett, M. Shankar, N. Pistianis, B. Guenther, and D. Brady, "Sequence Recognition Algorithm for Lightweight Single Person Tracking using Pyroelectric Infrared Boundary Sensors", Submitted to IEEE Sensors, 2005.

b. Conference Proceedings:

i. Burchett, J., M. Shankar, S. Feller, and D.J. Brady. Efficient human pose tracking using multiplex sensing, Source: Proceedings of SPIE - The International Society for Optical Engineering, PART 2, Sensors, and Command, Control, Communications, and Intelligence (C31) Technologies for Homeland Security and Homeland Defense III. 2004.

ii. Yunhui Zheng, D.J. Brady, M.E. Sullivan and B.D. Guenther, "Fiber Optical Localization by Geometric Space Coding with 2D Gray Code.

iii. Mohan Shankar, John Burchett, S.D. Feller, Brandon Jones, Russell Swagart, B.D. Guenther, D.J. Brady, "Biometric Tracking with Coded Pyroelectric Sensor Clusters"

iv. J.B. Burchett, Mohan Shankar, S.D. Feller, and D.J. Brady, "Efficient Human Pose Tracking using Multiplex Sensing"

c. Presentations:

i. E, Cull, D. Kowalski, J. Burchett, S. Feller and D. Brady, "Three-dimensional imaging with the Argus sensor array", Proceedings of ITCOM in Boston, MA, 2002.

ii. S. Feller, E. Cull, D. Kowalski, K. Farlow, J. Burchett, J. Adleman, C. Lin, and D. Brady, "Tracking and imaging humans on heterogeneous infrared sensor array for tactical applications.", Proceedings, SPIE Aerosence in Orlando, FL November 2002.

iii. J. Burchett, M. Shankar, S. Feller, and D. Brady, "Efficient Human Pose Tracking using Multiplex Sensing", Proceedings, SPIE Aerosense in Orlando, FL November 2003

iv. M. Shankar, J. Burchett, S. Feller, B. Jones, R. Swagart, B.D. Guenther and D. Brady, "Biometric Tracking with Coded Pyroelectric Sensor Clusters", SPIE Aerosense in Orlando, FL, November 2004.

(d) Manuscripts submitted but not published: None

(e) Technical reports submitted to ARO

    i. Yunhui Zheng, "Efficient Object Localization and Tracking with Discrete Spatial Mappings," Duke University, May 2005

    ii. "Multiple human tracking and identification with wireless distributed pyroelectric sensors," Duke University, May, 2006

(7) Scientific Personnel

d. David Brady
e. Yunhui Zheng – PhD
f. M. Shankar – MS
g. J. Burchett – PhD
h. S. Feller
i. B. Jones – BS
j. R. Swagart – BS
k. B.D. Guenther
l. M.E. Sullivan
m. N. P. Pistianis
n. J.-S. Fang - PhD
o. Q. Hao - PhD

(8) Inventions

"SENSOR SYSTEM FOR IDENTIFYING AND TRACKING MOVEMENTS OF MULTIPLE SOURCES"

(10) Appendixes (see attachments)

a) **Publications on Human Tracking and Recognition Contents**
b) **Final Report on Fiber Optic Interspatial Sensors**
c) **A Biometric System for Real-Time Walker Recognition Using a Pyroelectric Infrared Sensor and a Frensel Lens Array**